Intracorporeal Lithotripsy

a report by
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The remarkable progress of endourology over the past two decades can mostly be attributed to the reduction in size of the instruments and developments in the modalities for stone fragmentation. Endourology has come a long way from the original ureteroscopy performed by Young in 1912 (using a paediatric cystoscope), with the current generation of rigid and flexible ureteroscopes as well as tools for percutaneous nephrolithotomy (PCNL). The therapeutic armamentarium available for intracorporeal stone fragmentation includes pneumatic (ballistic), electrohydraulic, ultrasonic and laser lithotripsy. Although extracorporeal shock-wave lithotripsy (ESWL) has established itself for non-invasive stone fragmentation, the need for intracorporeal treatment remains, with either antegrade or retrograde access to reach the stone.

Pneumatic Lithotripsy

The first clinically available 'ballistic' device was the Swiss LithoClast® (EMS, Switzerland), which was introduced in the 1990s.[1] This was followed by the introduction of another pneumatic device, the electrokinetic lithotriptor (EKL).[2] The LithoClast uses air pressure to move a projectile, which in turn accelerates the metal endpiece and propels this like a jackhammer against the stone. The EKL device also involves projectile movement, but uses electromagnetic energy to oscillate a metal probe through a hollow cylinder. Small clinical studies have compared these energy sources with regard to stone-free rates, fragmentation time and proximal migration, with no consistent differences demonstrated between the modalities.[3,4] The quoted overall stone-free rate ranges from 70 to 95%.[5] A newer version of the LithoClast has been launched recently: the Swiss LithoClast System 2 (EMS, Switzerland), which allows simultaneous fragmentation and ureteral suction.

The main drawback to ballistic lithotripsy is the risk of proximal migration of stone fragments, for which an antegrade occlusion balloon catheter or a 'stone cone' can be deployed. A recent comparison of laser lithotripsy with the LithoClast 2 has also shown equivalent rates of stone clearance, migration and morbidity.[6] Another drawback of the traditional intracorporeal lithotriptor energy sources is that they require access to external electrical power or compressed air pipelines. Therefore, there is interest in a recent development, the Stonebreaker™ (LMA Urology, Switzerland), which weighs 500g and is powered by high-pressure carbon dioxide in cartridge form (see *Figure 1*). It delivers pressure up to 2.9MPa at the probe tip, and causes fragmentation by a jackhammer effect without the need for external electrical or pneumatic connections.[7] Along with its portability, the Stonebreaker offers versatility of use during both PCNL and ureteroscopic procedures, with no evidence of mucosal injury in the study of 102 patients described by Rané et al.[7]

Along with improvements (reduction in size) of the ureteroscopes, there have been advances in the equipment used to extract the stone fragments, which are more commonly produced with ballistic lithotripsy (in comparison with laser lithotripsy, which tends to reduce stones to dust). These graspers (e.g. triradiate) and baskets can be deployed safely within most ureteroscopes, and even dismantled if necessary. The availability of these tools increases the likelihood of stone clearance following successful stone fragmentation.

Ultrasonic Lithotripsy

Ultrasonic lithotripsy is predominantly undertaken via rigid instruments, and is generally used during PCNL. Its action is produced by the vibration of piezoelectric crystals within the hand-piece and transmission of this energy (up to 27kHz) through an attached probe. While ultrasound is often favoured due to its function in simultaneous stone fragmentation and clearance of fragmentation products (by suction), it may fail to fragment harder stones such as calcium oxalate monohydrate or some cysteine stones. As a result, a combination of ultrasound and lithoclast is sometimes used, but alternating between the energy modalities can be cumbersome. This problem is addressed by newer instruments such as the LithoClast Ultra® or the LithoClast Master®, which incorporate both energy sources. *In vitro* studies have demonstrated superior fragmentation efficiency with this combination device compared with ultrasound and pneumatic devices in isolation, with optimal settings of 12Hz (pneumatic) and 100% (ultrasound).[8,9]

Following concerns about overheating and malfunction at the highest energy settings with the LithoClast Ultra, a novel ultrasonic device

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Figure 1: StoneBreaker™

Figure 2: Cyberwand™

called the Cyberwand® (see *Figure 2*) has been developed. This has a dual-probe design with the two probes vibrating at different frequencies, and has been shown to have a significantly faster stone penetration time than the LithoClast Ultra (4.6 versus 8.1 seconds).[10]

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Electrohydraulic Lithotripsy

The underlying principle of this spark-gap generator is that ignition creates a spark that vaporises water into a gaseous bubble, expansion and collapse of which lead to shock-wave generation. Developed in the 1950s at the University of Kiev as a 9Fr probe, it was initially used to fragment bladder stones. Electrohydraulic lithotripsy (EHL) was then applied in the kidney by Raney[11] in the 1970s, but it was not until the late 1980s that 3Fr EHL probes were developed that could be passed through 9Fr and 11Fr flexible ureterorenoscopes; subsequently, smaller-calibre 1.9Fr probes have been described.[12]

Although EHL can technically be used during either PCNL or ureteroscopy, the technique is associated with more tissue trauma and bleeding than newer energy sources such as lasers. The quoted stone clearance rates are 83% for the distal ureter, 90% for the mid-ureter and 70% for the proximal ureter, all of which are marginally inferior to the newer modalities.[13] The key advantage over pneumatic lithotripsy is the malleability of the EHL probe (much like a laser fibre), which allows retrograde upper tract work.

Laser Lithotripsy

Laser technology has established itself as the most popular energy modality for ureteroscopy due to its versatility, the flexibility of the fibres and its ability to treat all types of stone. Stone fragmentation is effected by a photothermal effect at the stone surface. As the thermal effects of the laser are restricted to 0.5–1.0mm from the fibre tip, the risk of urothelial injury is minimised. The limitations are that the treatment takes a long time if there is significant stone burden.

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The most commonly used laser is the holmium: yttrium–aluminium–garnet (Ho:YAG) instrument, which operates at a wavelength of 2,150nm: stone-free rates are quoted at 98–100% in the distal ureter, 100% in the mid-ureter and 89–100% in the proximal ureter.[13] The Ho:YAG laser can also be used for transurethral enucleation or ablation in benign prostatic hyperplasia, contributing to its popularity within urology departments as a versatile investment. The complication rates are low, and the different fibre sizes (550, 365 and 200µm) allow treatment of both ureteric and renal stones.

Generally, most published guidelines (for example those of the European Association of Urology) advocate the use of retrograde treatment of stones up to 2cm in size, beyond which PCNL may be more suitable. However, a recent study comments on renal stones larger than 2cm being cleared by flexible ureterorenoscopy with a 200µm laser fibre with a 93% clearance rate, although it should be remembered that the operative time ranged from 45 to 140 minutes in this study.[14]

The first laser to be used was the pulsed-dye laser, which was introduced in the 1980s;[15] however, the high cost of coumarin dye and

its inefficiency at treating cystine stones prevented its popularisation. This laser is based on a wavelength of 504nm, pulsed at 1µs, with fibres of 200–320µm; overall stone-free rates are quoted at 84–90%.[5] Other lasers that have been described in treating stones include the thullium and the neodymium: YAG (Nd-YAG) lasers. A modification of the holmium laser is the development of the frequency-doubled, double-pulse Nd-YAG (FREDDY) laser; this induces generation of a plasma bubble, collapse of which generates a shock wave that produces stone fragmentation.[16] The use of lasers also depends on the theatre staff being adequately trained, as unlike the other energy modalities this type carries a small but real risk of injury to the user(s). Furthermore, the theatre must be appropriately modified, consistent with safe medical practice. These costs should be considered when initially investing in this technology, along with the relatively high cost of disposables.

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Economics

There is a paucity of data in the literature directly comparing modalities of intracorporeal lithotripsy, with most available studies comparing ESWL with PCNL or ureteroscopy (mostly in association with laser lithotripsy). Lotan and Pearle highlight the difficulties in translating economic conclusions across different countries and healthcare systems.[17] For example, in an economic survey by Chandhoke, charges for extracorporeal lithotripsy varied from US$373 to US$9,924, and for ureteroscopy from US$491 to US$8,108.[18] In another study across different countries, the cost of ureteroscopy and stone fragmentation ranged from US$160 in Germany to US$926 in the UK, US$1,685 in Italy and US$4,773 in the US.[19] There are numerous variables such as patient factors (stone location, size, etc.), need for hospitalisation, equipment costs (initial cost of machine, further disposables, maintenance, ancillary staff) and indirect costs, all of which makes it difficult to reach true economic conclusions. Nevertheless, depending on the country of purchase, currently the holmium laser machine costs around US$70,000, the LithoClast Master 2 around US$50,000 and the portable Stonebreaker around US$10,000; the cost of a laser fibre (US$250–500) is significantly higher than that of an EHL probe (US$200). These figures will obviously affect local practice based on financial circumstances.

Table 1: Summary of Available Intracorporeal Lithotriptors

Lithotriptor	Technique	Stone Contact	Resistant Stones	Thermal Injury
Ballistic	Projectile fired onto metal rod by pressurised air	Yes	None	No
Electrokinetic	Magnetic core projected onto metal rod by electromagnetic acceleration	Yes	None	No
Electrohydraulic	Shock wave generated under water through coaxial probe; 'microexplosions'	No (<1mm)	None	Yes
Ultrasonic	High-frequency vibration of metal probe; aspiration of fragments	Yes	Calcium oxalate monohydrate	Yes
Laser (Ho:YAG)	Solid-state laser	Yes	None	Yes

Ho:Yag = holmium yttrium–aluminium–garnet.

The use of lasers also depends on the theatre staff being adequately trained, as unlike the other energy modalities this type carries a small but real risk of injury to the user(s).

Conclusion

A range of energy modalities has been described for intracorporeal renal tract stone treatment. Deciding which modality to use where depends on user preference and regional health economics. ■

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